

## FIELD OF THE INVENTION

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of Fig. 3 showing a green sample frequency array, a very limited number of multiple sample frequency points are shown. The grey areas N are Nyquist areas. Theoretically that number is infinite. If the frequency spectrums overlap aliasing is introduced. If each spectrum around a sample frequency point does not overlap the so called Nyquist theorem is fulfilled: i.e. the incoming frequencies of the scene, via the optical system and the integrating light sensitive part of a sensor pixel, should be lower than half the sample frequency of each color. This means that the maximum resolution that each color can offer is determined by half the sample frequency of each color. So for the red and blue colored pixels the maximum resolution in the horizontal and vertical direction is  $f_{sRB}/2 = f_s/4$ , and in the diagonal direction  $\sqrt{2} * f_s/4$ . For the green pixels the diagonal resolution has a maximum of  $f_{sG}/2 = f_s/2\sqrt{2}$  and due to the quincunx structure in the horizontal and vertical direction of  $f_s/2$ .

Contour filtering is performed in order to obtain a contour signal that can be used to get a sharper image by enhancing the contour of the image. It is important that the contour filter does not interpret different RGB amplitudes as contours. Meaning that when filtering colored scene parts, having different RGB amplitudes, the output should be zeros.

When in a digital still camera a contour filter is applied a disadvantage is that the back folding aliasing artefacts described above will be enhanced, making those artefacts even more visible.

## SUMMARY OF THE INVENTION

It is an object of the present invention to solve the above-mentioned problem by providing an improved contour filtering where a more sharpened picture without amplifying the aliasing artefacts is obtained.

Another problem using Bayer sensors is the so-called green-green differences. The different colored neighbors of a green pixel cause green-green differences or green non-uniformity, in RGB Bayer sensors in the vertical direction. In the vertical direction of a 'red' column a green pixel has only red neighbors, while in 'blue' column green has only blue neighbor pixels. Depending on the quality of the vertical color separation of the sensor, the green pixel can be modulated by the red and blue pixels due to electron charge in the silicon layer or light crosstalk in the color filter layer. If so, then for certain colored scenes this will result in a column wise green non-uniformity.



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## BRIEF DESCRIPTION OF THE DRAWINGS

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Fig. 8 shows the fulfillment of the extended rule 2 for a 5x5 array;

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Fig. 9 shows the RGB and contour reconstruction, matrix and white balance of

Fig. 10 shows a block diagram for RGB reconstruction and the aliasing free

## DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention relates to a contour filter for filtering an image signal

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The filter is a 5x5 and in a preferred embodiment the coefficients of the 5x5

$$\begin{array}{ccccc} -0 & -1 & -2 & -1 & -0 \\ -1 & -0 & +2 & -0 & -1 \\ -2 & +2 & +8 & +2 & -2 \\ -1 & -0 & +2 & -0 & -1 \\ -0 & -1 & -2 & -1 & -0 \end{array}$$

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sigmawCR=8

sigmawCR is the factor by which the signal output of this contour filter has to be divided in order to achieve an almost unity signal amplitude.

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It should be noted that it is not the coefficients of the filter which are the ratio between the coefficients. Any 5x5 contour filter in which the coefficients have a mutual ratio corresponding to the above can be used. Therefore any filter which meets the criteria below is within the current invention:

$$\begin{array}{ccccc} -0 & -1x & -2x & -1x & -0 \\ -1x & -0 & +2x & -0 & -1x \\ -2x & +2x & +8x & +2x & -2x \\ -1x & -0 & +2x & -0 & -1x \\ -0 & -1x & -2x & -1x & -0 \end{array}$$

It should also to be noted that a slight deviation (e.g. 25%, but preferably

Finally, when changing the coefficients, the value of  $\sigma_{wCR}$  also has to be changed correspondingly in order to maintain the almost unity signal amplitude.

The transfer characteristic of the filter according to the invention is shown in Fig. 4. The zero transfer on and between the RGB sample frequencies is the reason why this filter tends towards an aliasing free contour with a minimum of distortion. This effect was confirmed by the finding of the contour of a zone plate which also showed that there was no contour in the red/blue and green aliasing domain.

With more than just slight changes to some coefficients, as shown below, the resulting contour will differ completely and the requirement will not be fulfilled. The coefficients of a contour filter B has been chosen in such a way that the ratio between the coefficients differs from the filter according to this invention. The coefficients of contour filter B are:

$$\begin{array}{ccccc} -0 & -1 & -1 & -1 & -0 \\ -1 & -1 & +2 & -1 & -1 \\ -1 & +2 & +8 & +2 & -1 \\ -1 & -1 & +2 & -1 & -1 \\ -0 & -1 & -1 & -1 & -0 \end{array}$$

sigmawCR=8

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In Fig. 5 the transfer characteristics of contour filter B are shown, and it can be seen that it will not be able to remove the aliasing from the contour signal since the transfer between the RGB sample frequencies are not zero. This was confirmed with a zone plate which also showed that there were contour in the red/blue and green aliasing domain.

Now it has been shown that the filter according to the invention solves the aliasing problem. However, in order to function properly no contour ('modulation') should occur in equal colored scene parts, although the RGB amplitudes will differ to a large extent there.

A suitable figure to test this is the color bar scene in Fig. 6 which uses the maximum available color space and as a consequence offers the largest differences in RGB

amplitudes. From the top to the middle the RGB amplitudes increase from 0-100%. Just beyond the middle the amplitudes drop to 90% after which the brightness of the RGB signals increases from 0-90%, resulting in a white color at the bottom line.

On the left side of Fig. 7 the result of the aliasing free contour is shown without any visible 'modulation' in the colored areas. On the right side the contour of contour filter B is shown with a clearly visible amount of undesired 'modulation'.

Additionally, tests have shown that the contour filter has no green-green differences. This can be shown by checking the filter according to rules that have to be fulfilled when designing contour filters without green-green differences.

The rules are:

**1. The center coefficient in both the first array of filter coefficients and the second array of filter coefficients is zero, and**

The center green data are added to the filter later using the green signal of the reconstruction path. This center green has already a restored green uniformity as has been explained before.

**2. The subtraction of neighboring diagonal filter coefficients in each of the first and second array of filter coefficients results in a zero contribution,**

This will average and as a consequence eliminate the green-green differences of the green pixels with vertical red and blue neighbors.

Finally, the combination of both filters should be checked in order to achieve a minimum of distortion. First their amplitude transfer should be checked and, if necessary, adapted for a minimal distortion in the total contour signal. Then, their amount of noise reduction by means of coring should possibly be matched by adjusting the coring level of each filters.

In order to check those rules for the aliasing free contour filter, its coefficients are splitted into weighting factors for 'center green is absent' and for 'center green is present'. When green is absent the following coefficients apply:

$\sigma_{wCR}=8$ 

sigmawCR=8

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- the sum of coefficients in a subgroup comprising every second row of said array of filter coefficients is zero and each filter coefficient not being a part of said subgroup is 0.

In Fig. 8 it can be seen that the contour filter according to the invention fulfils alternative rule.

For a near white luminance signal in the reconstruction block, derived from the RGB pixels of the image sensor, the matrix and white balance parameters have to be taken into account. Since the matrix and white balance are located after the reconstruction, some adaptation of the incoming red and blue colors is necessary. For this purpose the parameters SmartGcntrlR and SmartGcntrlB are used to control the red and blue amplitudes in order that they match with green and result in a near white luminance signal  $Y_n$ . Referring to Fig. 1, the following applies to this  $Y_n$ -signal in case of red and blue pixels:

$$\begin{aligned} Y_n[i,j] &= \text{SmartGcntrlR} * \text{red} \\ Y_n[i+1,j+1] &= \text{SmartGcntrlR} * \text{blue} \end{aligned}$$

In case of green pixels  $Y_n$  is equal to green.

Yn[i+1,j] = green  
Yn[i,j+1] = green

In Fig. 9 a simplified block diagram is shown with the RGB and aliasing free contour reconstruction, followed by the matrix and the white balance. This block diagram is used to define the parameters in the next formulas for the calculation of SmartGcntrlr/B. Light LS from a scene is passed to an RGB Bayer sensor S thru a lens L. An output signal from the sensor S is applied to a CDS (correlated double sampling, agc (automatic gain control) and ADC (analog to digital conversion) processing block 1. An output of the processing block 1 is applied to an RGB reconstruction and parallel contour processing block 3. The processing block 3 outputs reconstructed RGB signals  $R_i$ ,  $G_i$  and  $B_i$ , as well as an aliasing-free contour signal AFC. The reconstructed RGB signals  $R_i$ ,  $G_i$  and  $B_i$  are applied to a matrix circuit MX that produces signals  $R_o$ ,  $G_o$  and  $B_o$ , which are applied to a white balance circuit WB to furnish output signals  $R_o'$ ,  $G_o'$  and  $B_o'$ .



A correction of each RGB Bayer color sensor's primary colors into the EBU primaries which are accustomed in worldwide television sets and PC monitors is necessary. The correction is realized with a matrix which requires nine multipliers.

$$\begin{bmatrix} Ro \\ Go \\ Bo \end{bmatrix} = \begin{bmatrix} a11 & a12 & a13 \\ a21 & a22 & a23 \\ a31 & a32 & a33 \end{bmatrix} \times \begin{bmatrix} Ri \\ Gi \\ Bi \end{bmatrix}$$

- 5 Ro, Go, Bo are the output RGB signals of the matrix and Ri, Gi, Bi the input signals.

With the white balance after the matrix, the RGB signals become:

$$Ro' = awbR \cdot Ro$$

$$Go' = Go$$

$$Bo' = awbB \cdot Bo$$

- 10 where awbR and awbB are the white balance parameters. (According to the World Gray Assumption method (WGA),  $awbR = \text{totalGreen} / \text{totalRed}$  and  $awbB = \text{totalGreen} / \text{totalBlue}$ , where totalRed, totalGreen and totalBlue represent the total of the RGB color amplitudes measured over the whole scene.) Both actions, the matrix together with the white balance, offer the desired white reproduction. The Ro', Go', Bo' signals now guarantee an EBU color reproduction.

- 15 For a proper near white luminance signal Yn the opposite has to be done. Therefore, imagine a scene with colors according to the EBU color space and a color temperature equal to D65 white. With the inverse matrix of the one shown below, the color space of the sensor is achieved:

$$\begin{bmatrix} Rii \\ Gii \\ Bii \end{bmatrix} = \begin{bmatrix} b11 & b12 & b13 \\ b21 & b22 & b23 \\ b31 & b32 & b33 \end{bmatrix} \times \begin{bmatrix} Ri \\ Gi \\ Bi \end{bmatrix}$$

- 20 where Rii, Gii, Bii represent the colors of an EBU scene and Ri, Gi, Bi the colors of the sensor.

For the luminance signal Yn only the white reproduction of the inverse matrix is of interest, being represented by the sum of the matrix coefficients of each color.

$$\Sigma Rii = b11 + b12 + b13$$

$$\Sigma Gii = b21 + b22 + b23$$

$$\Sigma Bii = b31 + b32 + b33$$

- 25 In addition, the color temperature of the scene need not be D65 white. Inclusive an arbitrary color temperature the sum of the matrix coefficients becomes:





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Although the present invention has been described in connection with the preferred embodiment, it is not intended to be limited to the specific form set forth herein. On

the contrary, it is intended to cover such alternatives, modifications, and equivalents, as can be reasonably included within the scope of the invention as defined by the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps  
5 other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention can be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means can be embodied by one and the same item of hardware. The mere fact that certain  
10 measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.